Telecommunication Systems Performance Assessment

Telecommunication system performance usually is understood to be either specifications of the communication performance requirements of a user or characterization of the performance provided by a particular communication system or service. The Institute assesses the performance of a variety of communications transmission systems and digital communications networks. Assessment tools developed by the Institute include automated analysis techniques, used during the system-design process for predicting performance of a telecommunication system in any specified environment, and test and measurement systems for evaluating the performance of either prototype or operational transmission systems and networks.

These tools are used to evaluate the performance of a variety of voice, data, and video telecommunication systems that may be entire networks or specific transmission links. These assessments address performance for a wide variety of transmission media, including terrestrial radio and satellite transmission systems and wireline systems such as local area networks (LANs). Both hardware and software models are used to develop and verify transmission system designs and to evaluate system performance.

Specific assessments conducted during FY 96 included expansion of the Jammer Effectiveness Model to include radar systems; development and application of methods to evaluate performance requirements for satellite-based, broadband communications networks; development of methods to test advanced HF radio systems; and traffic-flow modeling of LAN interconnection scenarios.

Areas of Emphasis

Radio System Design and Performance Software

The Institute expanded the Jammer Effectiveness Model to include radar systems performance, as well as communication system analysis, in jamming environments and adapted the model to run as a Windows application. Projects are funded by the U.S. Army National Ground Intelligence Center.

Satellite Studies

The Institute uses the Advanced Communications Technology Satellite (ACTS) to determine and evaluate requirements for performance, interface, and interoperability standards for satellite-based, broadband communications networks. Projects are funded by NTIA and the National Communications System (NCS).

Advanced HF Testing and Evaluation

The Institute produced a set of 13 audio compact disks that provide both clean and degraded tones for HF radio automatic link establishment. The Institute continues to develop and use a laboratory test bed to evaluate HF modems and associated protocols, and participate in developing and using an international field test bed to conduct over-the-air tests in support of Federal standards for adaptive HF radios. Projects are funded by NCS.

Network Flow Modeling

The Institute develops computer-based modeling and simulation tools to study the performance of large-scale data communication networks as a function of network capacity and offered traffic. Projects are funded by NTIA and the U.S. Army.

Radio System Design and Performance Software

Outputs

- Current version of the Jammer Effectiveness Model for communications analysis in use by the U.S. Army.
- Additional version of the Jammer Effectiveness Model for radar analysis under further development for the U.S. Army.

The Jammer Effectiveness Model (JEM) was expanded in FY 96 to include not only communication systems analysis in a jamming environment, but also radar systems performance in a jamming environment. The latest version of JEM runs as a Windows application and is user-friendly and menu-driven. This model is highly structured and modular in design, which allows for greater flexibility and expandability. The radar analysis capability is obtained by creating a separate version of JEM with the appropriate models for radar calculations. The analysis and design capability of this program was available previously only on mainframe computers.

The JEM version developed as a communications analysis model is used primarily by the U.S. Army to model communication systems in electronic warfare scenarios. The model includes a user-created catalog of equipment, ground stations, aircraft and satellite platforms; the software for creating and maintaining this catalog; a climatological database for much of the world; a library of propagation subroutines; and the analysis software. Current scenario types that can be analyzed are ground-to-ground, ground-to-satellite, ground-to-aircraft, aircraft-to-satellite, jamming from an airborne or ground jammer, and jammer versus network from an airborne or ground jammer. The communication links or network being jammed can have transmitters or receivers either airborne or ground-based. The jammer versus network scenario has been modified recently to handle multiple jammers.

The JEM propagation library includes subroutines for use in calculating clear-air attenuation, rain attenuation, multipath attenuation, diffraction losses, and troposcatter losses. The valid frequency range of JEM currently is from 2 MHz to 300 GHz and includes complete analysis capability for both the jamming and the jammer versus network model scenarios.

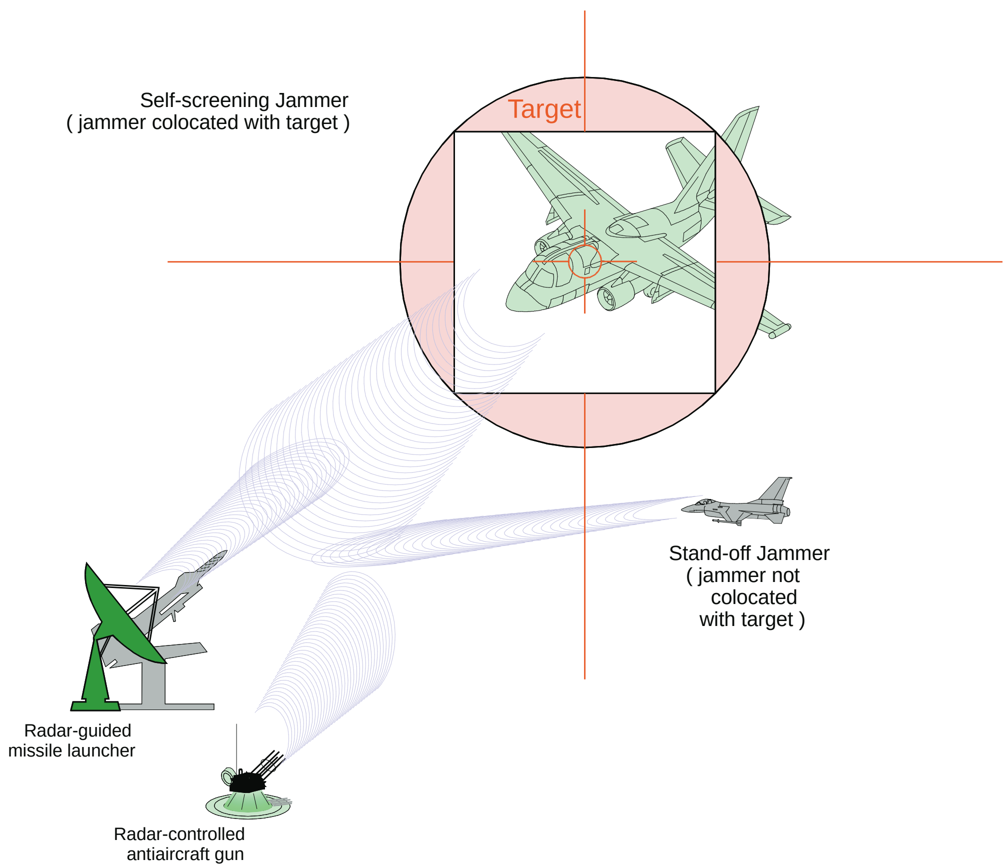
Data entry in the JEM is simplified by user-friendly menus and options. Databases are created as a result of this data entry and saved as scenario descriptions. These scenario descriptions completely characterize the communication link or jamming situation. The scenario description includes ground or airborne station location and physical factors such as climate and terrain. Each of the analysis programs within a scenario analyze the case represented by the scenario description data.

The communications analysis version of JEM is organized into six scenarios. A scenario represents either a communication path geometry description or a jamming geometry description. The four scenario types in the communication geometry description are: ground-to-ground, ground-to-satellite, ground-to-aircraft, and aircraft-to-satellite. The two scenario types in the jamming geometry description are jamming and jammer versus network. The jamming scenario analyzes: received jammer power versus distance, received transmitter power versus distance, jammer footprint, and isopower contours. The jammer versus network scenario analyzes and evaluates the effects of up to three jammers on up to five communications nodes. For the jamming geometry description, the receiver, transmitter, and jammer platforms can be on the ground or airborne. The jamming and jammer versus network scenarios are the major features of JEM for electronic warfare and interference analysis. The other four scenarios are used as an aid in evaluating and designing microwave communication systems. They allow the user to simulate a wide variety of propagation effects on the system that occur in the higher-frequency ranges by including clear-air absorption losses and losses due to rain attenuation. The user can perform several different analyses on the data without re-entering it.

The radar version of JEM that is currently under development will allow radar analysis of different combinations of radars and jammers that are on the ground or carried by airborne stations. The radar analyses consist of either performance evaluation of a radar trying to detect and track a target, or evaluation of the ability of a synthetic aperture radar to map a location. The analysis can be performed both with and without the presence of a jammer. One scenario includes the jamming of an airborne radar by a ground-based or airborne jammer to protect potential targets that either can be collocated with the jammer or separated from the jammer. A second scenario involves the jamming of a synthetic aperture radar on an airborne platform from either an airborne or ground-based jammer platform. Deception jammers, false target generators, and broadband noise jammers are all included in the analysis models. The three-dimensional geometry of these radar scenarios will require three-dimensional antenna patterns, which are also included in the analysis models.

There are three analysis modes available in the radar jamming scenario: a radar jammer footprint, a radar isopower contour, and a radar burn-through range. For the radar jammer footprint analysis, a jammer is able to jam a radar that is on or within a contour of distance to jammer versus azimuth angle, and prevent it from detecting a target. The isopower contour analysis is a plot of signal power density about the radar or jammer versus distance and azimuth angle about the radar or jammer. The radar burn-through range analysis is the minimum range to the target versus azimuth angle at which the target is obscured by jamming. It also is the maximum range versus azimuth angle at which the radar detects the target.

The Figure illustrates a stand-off and self-screening airborne jammer attempting to avoid detection by a ground-based radar. The ground-based radar will direct missiles and antiaircraft guns to destroy the target aircraft. The stand-off jammer is protecting other airborne targets by jamming the ground-based radar. The self-screening jammer is protecting itself from detection by the ground-based radar.



A stand-off and self-screening jammer avoiding detection by enemy ground-based radar.

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Satellite Studies

Outputs

- Advanced satellite capabilities for National Security Emergency Preparedness.
- Satellite standards development.
- PEACESAT system engineering support.

Satellites have distinct advantages over terrestrial telecommunication facilities in a number of practical applications. Satellites have a natural broadcast capability: a single geostationary satellite can provide coverage ranging from a small region (e.g., a 160-km diameter circle) to almost an entire hemisphere of the earth. Satellites can economically support communications in remote areas, and can provide broad and highly reliable coverage to mobile stations. Temporary communications systems that must be deployed rapidly are often best served by satellites. Advanced satellites with electronically steerable "spot beam" antennas and on-board baseband switching can serve as "on-demand" backups for failed or overloaded links in a terrestrial network. The Advanced Communications Technology Satellite (ACTS), launched several years ago by the National Aeronautics and Space Administration (NASA), has provided opportunities to study (and optimize) innovative satellite technologies supporting these and other applications. ITS operates a regional ACTS earth station and test center that supports such experiments, and uses these ACTS facilities in its own satellite communications research.

The Institute's FY 96 Satellite Studies program focused on measurement of ACTS performance in supporting representative user applications. ITS staff members organized a four-party ACTS Collaboration when several ACTS experimenters determined that they had similar goals and interests. By combining equipment, the Collaboration formed a three-node satellite network (Figure 1) that includes ACTS earth stations and terrestrial connections and can support a wide range of experiments. ITS led the Collaboration, provided liaison with NASA and the National Communications System (NCS) Office of Programs, and performed one of the application experiments, which dealt with voice quality. The National Institute of Standards and Technology (NIST), Computer Systems Laboratory (CSL) performed application experiments on desktop conferencing and local area network (LAN) bridging. COMSAT Laboratories assisted NIST/CSL with satellite access, provided the frame relay software for the ACTS earth stations, and performed an experiment using Internet protocols. MITRE Corp. contributed to the design of experiments that were relevant to National Security Emergency Preparedness (NS/EP) communications needs and assisted the other collaborators with their experiments. NCS sponsored much of the work. The NCS mission to provide communications in support of NS/EP gave the Collaboration a common purpose.

The Institute's voice quality testing experiment applied an ITS-developed objective Voice Quality Assessment System in evaluating the user-perceived quality of satellite-derived voice channels. Mean opinion scores for the satellite-derived channels were shown to be nearly the same as those of terrestrial channels (excluding effects of delay). Tests of PC-based desktop video conferencing using relatively low-speed (256 kbit/s) ACTS channels showed that satellite delay and errors do not significantly degrade application effectiveness except for highly interactive functions, such as joint document manipulation. The LAN-bridging experiments examined ACTS performance in transferring large data files between computers located in LANs at each end of a satellite link. An example application is the retrieval of maps or weather information in an NS/EP scenario. In one experiment, the digital file of the weather map shown in Figure 2 was transferred. The

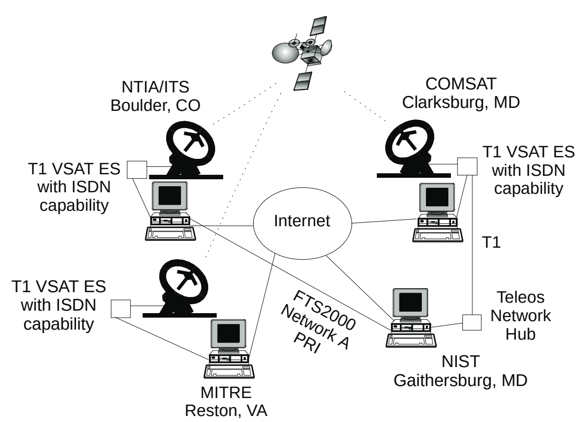

Figure 1. Experimental network including ACTS earth stations.

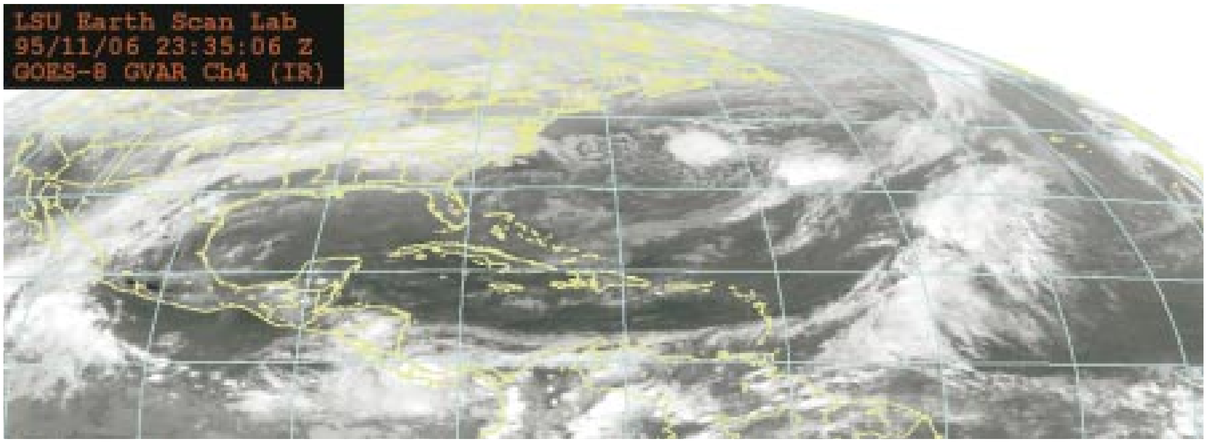

Figure 2. Image of a weather map used in LAN bridge and file transfer experiments.

experiment showed that satellite propagation delays can reduce throughput by as much as α when transmission control protocol (TCP) implementations not optimized for satellite communications are used. Bit-error rates less than 10^{-4} had negligible impact on the observed transfer rates.

TCP in its default form is relatively inefficient in transferring data over satellite channels, particularly at bit rates above 64 kbit/s. Modifications can be made to TCP to improve its performance for “long-fat” channels. Among these are an increased window size, more detailed round-trip-time tracking, and a process called slow start. Figure 3 shows throughput results measured in the Collaboration experiments for three versions of TCP. The lower curve shows the throughput for TCP with default parameters. The middle curve, for TCP with modified parameters, shows the improvement with an increased window size. The upper curve (for TCP-LFN) shows that with increased window size, more frequent round-trip time measurements, and slow start, TCP was able to make nearly full use of the available bandwidth. This protocol experiment also demonstrates the bandwidth-on-demand capability of ACTS.

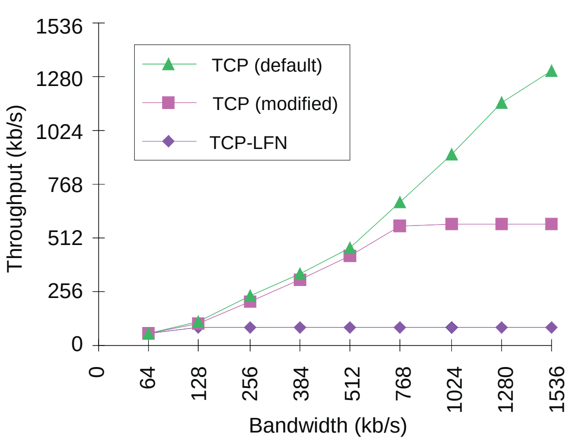

Figure 3. Throughput vs. bandwidth over ACTS for three versions of TCP/IP.

The interworking of satellite and terrestrial communications systems is of particular interest in the Satellite Studies program. During FY 96, ITS personnel began participating in two standards development organizations addressing satellite/terrestrial interface issues: Telecommunication Industry Association (TIA) Committee TR-34 (Satellite Equipment and Systems) and International Telecommunication Union-Radiocommunication Sector (ITU-R) Working Party 4B (Fixed Satellite Service). Contributions are focused on the performance of hybrid networks.

The Institute’s Satellite Studies program also supports the Pan-Pacific Education and Communication Experiments by Satellite (PEACESAT) program. This program was established in 1971 to provide teleconferencing and data communications for about 40 locations in 21 countries in the Pacific basin. It provides interisland communications to support education, telemedicine, emergency communications, and other applications promoting economic development. During FY 96, ITS supported NTIA in testing the PEACESAT system’s ability to accommodate new digital services. Results will allow more access to the Internet for PEACESAT users.

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Advanced HF Testing and Evaluation

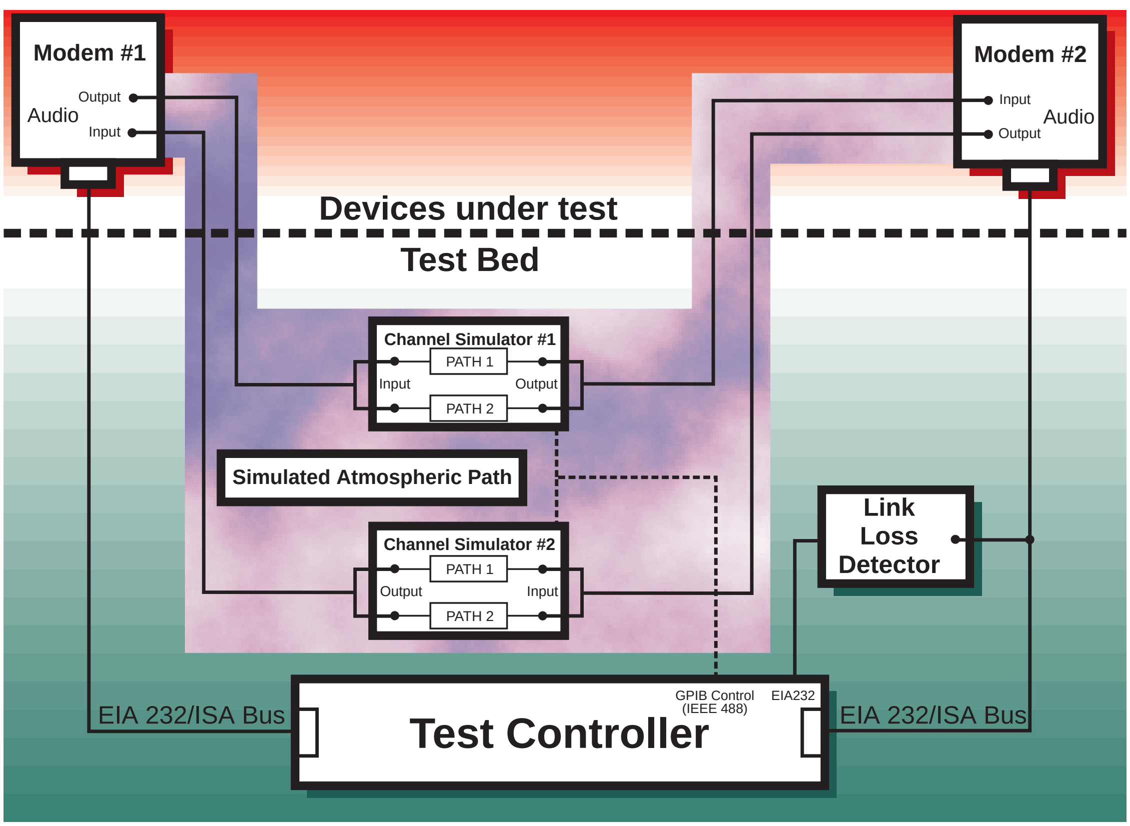
Outputs

- Facility for evaluating digital HF modems and protocols.
- Contributions to HF radio standards development.
- Audio compact disks for automatic link establishment interoperability testing.
- Anonymous FTP access to software for generating reference ALE tones.

The Federal Emergency Management Agency, the Department of Defense, and other Federal agencies depend heavily on HF radio to supplement wireline and satellite communications in natural disaster and national emergency situations. Communications efficiency and interoperability are vital in these situations, which increasingly require several different agencies to coordinate time-critical operations. HF radio technologies are being upgraded to meet these growing demands through innovations such as computer-controlled automatic link establishment (ALE). The Institute has contributed strongly to HF radio enhancement through laboratory and field testing of ALE and other HF technology advances.

The HF modem/protocol test bed at ITS supports this activity (see the Figure). The test bed's two narrowband HF channel simulators enable ITS engineers to subject HF modems and protocols to a wide range of controlled and repeatable channel conditions. The computer-based test controller permits extensive, unattended testing and allows experimental conditions to be changed with little or no equipment reconfiguration.

The Institute's HF simulation and laboratory test capabilities are supplemented by extensive field test facilities. During FY 96, ITS engineers continued cooperative work with counterparts in other organizations to develop an international test network for



HF modem/protocol test bed.

HF communications. The initial network will have nodes located at ITS, the Australian Defence Science and Technology Organization (Salisbury, South Australia), Rome Laboratories (Rome, New York), U.S. Navy NraD (San Diego, California), and Rockwell International (Richardson, Texas). The network is being developed in support of the National Communications System (NCS), which oversees Federal telecommunications standardization. NCS periodically solicits advanced HF radio technology contributions from Government and industry through announcements in the *Federal Register* and *Commerce Business Daily*. ITS and its partners will evaluate these and other technology contributions to advance the state-of-the-art in adaptive HF networking, high-speed data transmission, and reliable communications in stressed environments. Results will influence the development of national and international HF radio standards.

During FY 96, ITS personnel also continued the development of an HF radio ALE network simulation capability based on proposed Federal Standard 1046 ("Telecommunications: HF Radio Automatic Networking"). The efficiency, throughput, and delay of HF networks can be improved substantially through proper selection and use of advanced network features such as frequency scanning, sounding, polling, alternate or indirect routing, connectivity information exchange, automatic message exchange, and store and forward message exchange. However, these features have overhead implications and must be used carefully. Through computer simulation, ITS will study the impacts of these capabilities on network performance, both as an aid in preliminary evaluation of proposed standards and in support of over-the-air network tests. Results will aid users, designers, and system administrators in determining efficient network resource configuration and use.

Finally, ITS is developing test suites for assessing HF ALE protocol implementations. During FY 96, ITS engineers used an ALE protocol model, based on the ITS-developed Federal Standard 1045A ("Telecommunications: HF Radio Automatic Link Establishment") to create an innovative, effective, and economical ALE radio test product called the ALE Clean and Degraded Tones audio compact disk set. This set of 13 CDs includes one Clean Tones CD and 12 Degraded Tones CDs. The Clean Tones CD contains 65 tracks of calibration tones and ALE-specific signals. These signals correspond precisely to the Federal Standard 1045A specifications and are uncorrupted by transmission effects. Each Degraded Tones CD contains several tracks of calibration tones, followed by 25 tracks containing 100 calls. Each CD was created under varying simulated channel conditions (see the Table).

The Clean Tones CD has been used successfully in laboratory testing and has been distributed widely in the HF radio industry. The Degraded Tones CDs will be used to assess radio system compliance with probability-of-linking statistics specified in Federal Standard 1045A. The ALE CD set directly supports the continuing ITS function of HF radio performance and interoperability testing. It has proven to be very useful to HF radio vendors and users in interpreting and analyzing prototype implementations of the Federal Standard. ITS is providing continued support to the High Frequency Industry Association and other Government agencies in extending the ALE CD capabilities to meet the needs of both radio users and vendors.

The ALE CDs are now available to the public through NIST Special Databases. The Clean Tones CD is listed in the NIST Standard Reference Data Products Catalog 1995-96 (NIST Special Publication 782, 1995-96 Edition). The Degraded Tones CDs will be listed in the next edition of the catalog. For more information, phone (301) 975-2208, FAX (301) 926-0416, or e-mail SRDATA@enh.nist.gov.

The audio tones recorded on the CDs were created using an ITS-developed computer program called *alecall*. This program also can create sound files on a personal computer, which then may be output through a sound card. This ability to create ALE calls "on the fly" is useful for real-time laboratory testing and analysis. The *alecall* program is available to the public by anonymous FTP through the Internet. FTP to *ntia.its.bldrdoc.gov* and enter ftp as your user name and your full e-mail address as the password. Retrieve the readme.txt file from the /dist/ale-cd directory for detailed file instructions.

CD Channel Conditions

CD #	Channel Conditions	SNR (dB)
CD02-05	Gaussian Noise	-2.5 thru 0.0
CD06-08	CCIR Good	0.5 thru 8.5
CD10-13	CCIR Poor	1.0 thru 11.0

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Network Flow Modeling

Outputs

- Large-scale network simulation tools.
- Network component loading and message delay characterizations.
- Network planning recommendations.

Design of large-scale data communication networks requires quantitative means of relating offered traffic and network capacity with network performance characteristics such as message transfer delays. The Institute maintains several computer-based modeling and simulation tools that facilitate such studies. One of these tools, the ITS Network Flow Model (NFM), has been used to provide network planners with first-level estimates of network component loads and message transfer delays in several local area network (LAN) interconnection scenarios. The NFM is based on the Block Oriented Network Simulation (BONeS) software system.

A key requirement for the NFM is to produce network characterizations that reflect variations in user traffic over time. ITS has developed a flexible bimodal traffic generator for the BONeS system that controls the arrival of network messages in any hourly period over a 9-hr business day. The traffic generator produces traffic peaks during the midmorning and midafternoon hours, corresponding to the observed peaks in typical office activity. The message interarrival statistics are controlled by a Poisson process, which is used frequently in simulating human interactions with a system.

In a recent application, the NFM was used to examine traffic flows in a two-tier network interconnecting 2,500 users (Figure 1). In the modeled configuration, the first tier (backbone) network connects five subnetworks. Each subnetwork connects five user groups. Each user group has 100 users. Typically, each user group would be localized in a separate building or work area. The modeled backbone and second-tier networks could be either 10-Mbit/s Ethernet or 100-Mbit/s fiber-distributed data interface (FDDI) facilities. The structure of the model could be modified easily to represent any similar network architecture. The number of users in each group, the number of messages per day, the network

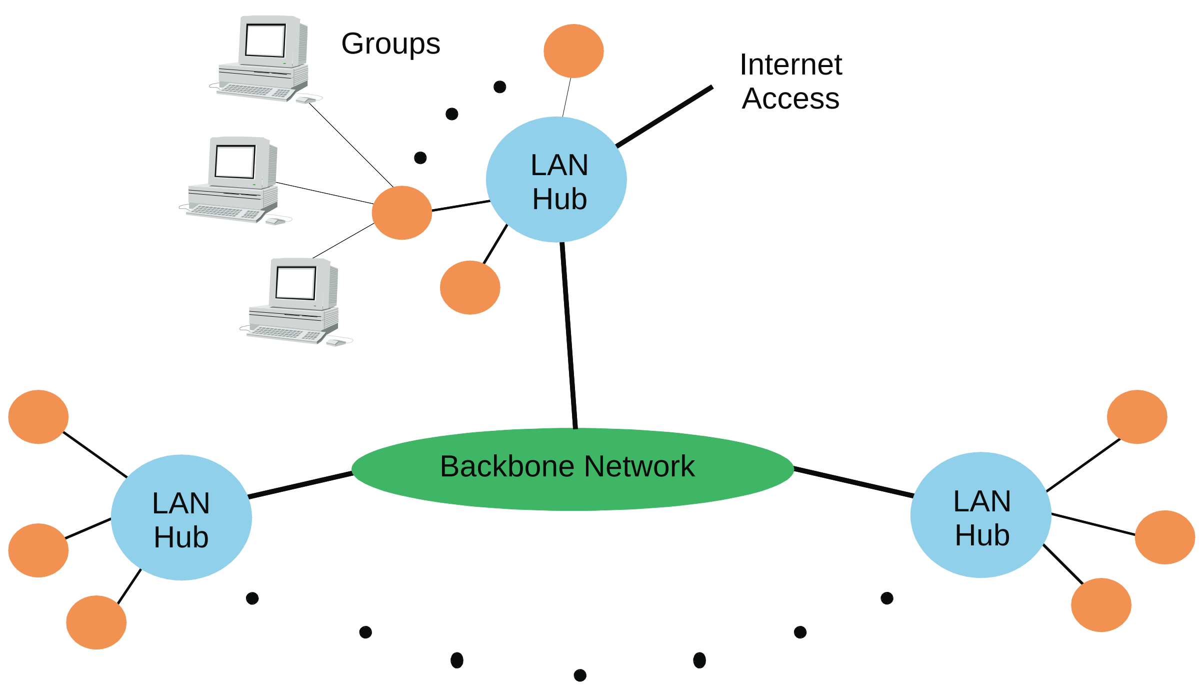

Figure 1. Two-tiered network examined by the Network Flow Model.

transmission speeds, and the lengths of individual messages are all variable input parameters.

Figure 2 shows a representative output of the NFM for the LAN interconnection scenario described. The plots depict average traffic loads on the 10-Mbit/s backbone network as a function of time for each of four message types (e-mail, server, ftp, and World Wide Web). The plots also show corresponding average and maximum loads for the four message types combined. The traffic data are aggregated on a second-by-second basis and are averaged over 60-s periods. The maximum load is the largest traffic level observed in any 1-s interval over the same 60-s period. At Ethernet speeds, the backbone LAN is saturated during peak periods, with averages well above the recommended 6 Mbit/s maximum. Figure 2 also demonstrates that e-mail traffic is the main contributor to the total load, as expected.

Figure 3 shows corresponding NFM simulation results for message transfer delays. In this example, the daily traffic load is approximately 150,000 messages for the 2,500 users. During peak traffic periods, delays that exceed 35 s could be experienced in the Ethernet network configuration. In the FDDI configuration, corresponding delays averaged 40-50 ms. Figure 3 also shows the delays of each LAN independently. The most sensitive LAN at the Ethernet speed is the backbone, which accounts for most of the long delays. ITS recommended that this network be considered as an upgrade to FDDI, since 30-s transmission delays are unacceptable for many interactive computer applications.

The data plotted in Figure 3 also show that larger delays are experienced during the afternoon peak period as compared to the morning peak period. This asymmetry is attributable to queuing effects. Network planners and system administrators must be sensitive to such effects in balancing traffic, capacity, and performance requirements to achieve cost-effective network designs.

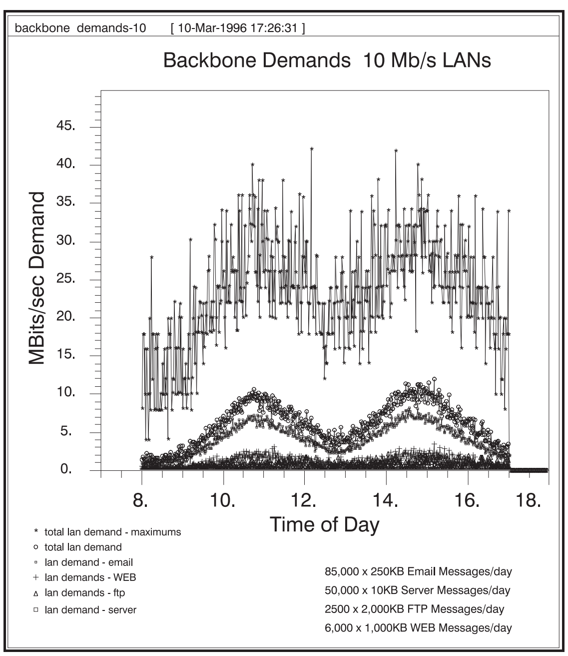

Figure 2. Network Flow Model simulation of local area network traffic loads.

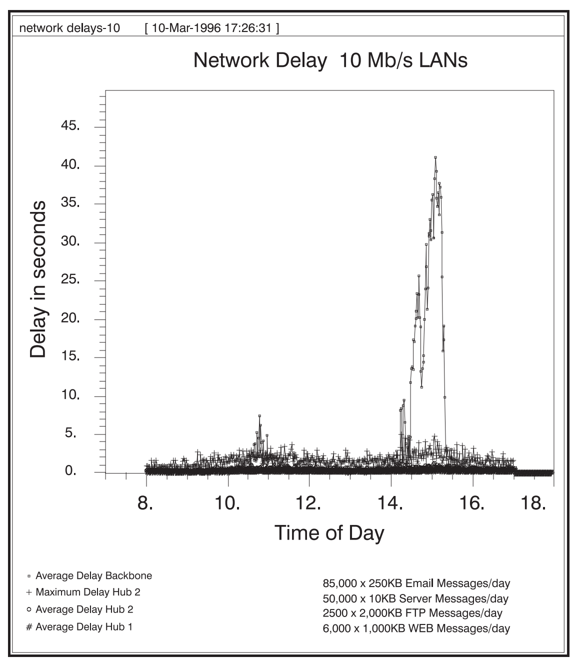

Figure 3. Network Flow Model simulation of message delays.

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